

(19) World Intellectual Property Organization  
International Bureau



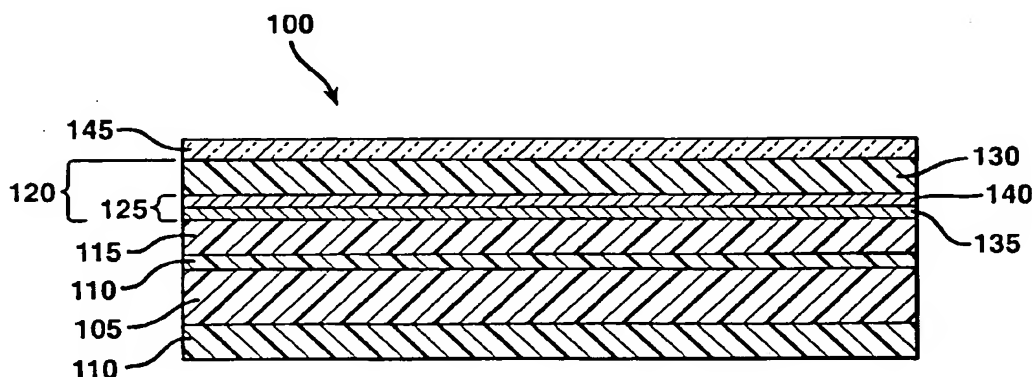
(43) International Publication Date  
1 November 2001 (01.11.2001)

PCT

(10) International Publication Number  
**WO 01/81649 A1**

- (51) International Patent Classification?: C23C 14/08, B05D 7/24, B65D 65/40
- (21) International Application Number: PCT/US01/06596
- (22) International Filing Date: 1 March 2001 (01.03.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
09/553,188 20 April 2000 (20.04.2000) US
- (71) Applicant: **BATTELLE MEMORIAL INSTITUTE** [US/US]; 902 Battelle Boulevard, Richland, WA 99352 (US).
- (72) Inventors: **GRAFF, Gordon, Lee**; 3750 Westlake Drive, West Richland, WA 99353 (US). **GROSS, Mark, Edward**; 50 Deseret Drive, Pasco, WA 99352 (US). **SHI, Ming, Kun**; 2500 George Washington Way, Richland, WA 99352 (US). **HALL, Michael, Gene**; 4125 Ironton Drive, West Richland, WA 99353 (US). **MARTIN, Peter, Maclyn**; 7703 West Thirteenth Avenue, Kennewick, WA 99338 (US). **MAST, Eric, Sidney**; 634 Chestnut Avenue, Richland, WA 99352 (US).
- (74) Agents: **PRIOR, Patricia, L.** et al.; Killworth, Gottman, Hagan & Schaeff, L.L.P., One South Main Street, Suite 500, One Dayton Center, Dayton, OH 45402-2023 (US).
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- Published:**  
— with international search report  
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: BARRIER COATING



(57) Abstract: A barrier assembly. The barrier assembly includes at least one barrier stack having at least one barrier layer and at least one polymer layer. The barrier stack has an oxygen transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 23 °C and 0 % relative humidity, and an oxygen transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 38 °C and 90 % relative humidity. The barrier stack also has a water vapor transmission rate of less than 0.005 g/m<sup>2</sup>/day at 38 °C and 100 % relative humidity. A method for making a barrier assembly is also disclosed.

WO 01/81649 A1

-1-

## BARRIER COATING

The present invention relates generally to barrier coatings, and more particularly to barrier coatings having improved barrier properties.

Many different types of products are sensitive to gas and liquids, which can  
5 cause deterioration of the product or render it useless, including electronics, medical devices, and pharmaceuticals. Barrier coatings have been included in the packaging for these environmentally sensitive products to protect them from gas and liquid transmission. As used herein, the term environmentally sensitive means  
10 products which are subject to degradation caused by permeation of environmental gases or liquids, such as oxygen and water vapor in the atmosphere or chemicals used in the processing, handling, storage, and use of the product.

Plastics are often used in product packaging. However, the gas and liquid permeation resistance of plastics is poor, often several orders of magnitude below what is required for product performance. For example, the oxygen transmission  
15 rates for materials such polyethylene terephthalate (PET) are as high as 1550 cc/m<sup>2</sup>/day/micron of thickness (or 8.7 cc/m<sup>2</sup>/day for 7 mil thickness PET), and the water vapor transmission rates are also in this range. Certain display applications using environmentally sensitive display devices, such as organic light emitting devices, require encapsulation that has a maximum oxygen transmission rate of  
20 10<sup>-4</sup> to 10<sup>-2</sup> cc/m<sup>2</sup>/day, and a maximum water vapor transmission rate of 10<sup>-5</sup> to 10<sup>-6</sup> g/m<sup>2</sup>/day.

Barrier coatings have been applied to plastic substrates to decrease their gas and liquid permeability. Barrier coatings typically consist of single layer thin film inorganic materials, such as Al, SiO<sub>x</sub>, AlO<sub>x</sub>, and Si<sub>3</sub>N<sub>4</sub> vacuum deposited on  
25 polymeric substrates. A single layer coating on PET reduces oxygen permeability to levels of about 0.1 to 1.0 cc/m<sup>2</sup>/day, and water vapor permeability to about 0.1 to 1.0 g/m<sup>2</sup>/day, which is insufficient for many display devices.

Barrier coatings which include alternating barrier layers and polymeric layers have been developed. For example, U.S. Patent Nos. 5,607,789 and 5,681,666  
30 disclose a moisture barrier for an electrochemical cell tester. However, the claimed

-2-

moisture barrier ranges from 2 to 15 micrograms/in<sup>2</sup>/day which corresponds to a rate of 0.003 to 0.023 g/m<sup>2</sup>/day. U.S. Patent No. 5,725,909 to Shaw et al. discloses a coating for packaging materials which has an acrylate layer and an oxygen barrier layer. The oxygen transmission rate for the coating was reported to be 0.1

5 cc/m<sup>2</sup>/day at 23°C and the water vapor transmission rate was reported to be 0.01 g/m<sup>2</sup>/day in

D. G. Shaw and M. G. Langlois, Society of Vacuum Coaters, 37<sup>th</sup> Annual Technical Conference Proceedings, p. 240-244, 1994. The oxygen transmission rates for these coatings are inadequate for many display devices.

10 Thus, there is a need for an improved, lightweight, barrier coating, and for methods for making such a barrier coating.

The present invention meets these needs by providing a barrier assembly and a method for making such an assembly. The barrier assembly includes at least one barrier stack having at least one barrier layer and at least one polymer layer. The

15 barrier stack has an oxygen transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 23°C and 0% relative humidity, and an oxygen transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 38°C and 90% relative humidity. It also preferably has a water vapor transmission rate of less than 0.005 g/m<sup>2</sup>/day at 38°C and 100% relative humidity.

Preferably, the barrier layers of the barrier stacks are substantially

20 transparent. At least one of the barrier layers preferably comprises a material selected from metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof.

The barrier layers can be substantially opaque, if desired. The opaque barrier layers are preferably selected from opaque metals, opaque polymers, and

25 opaque ceramics.

The barrier assembly can include a substrate adjacent to the at least one barrier stack. By adjacent, we mean next to, but not necessarily directly next to. There can be additional layers intervening between the adjacent layers. The substrate can either be flexible or rigid. It is preferably made of a flexible substrate

30 material, such as polymers, metals, paper, fabric, and combinations thereof. If a

rigid substrate is used, it is preferably a ceramic (including glasses), a metal, or a semiconductor.

The polymer layers of the barrier stacks are preferably acrylate-containing polymers. As used herein, the term acrylate-containing polymers includes acrylate-  
5 containing polymers, methacrylate-containing polymers, and combinations thereof. The polymer layers can be the same or different.

The barrier assembly can include additional layers if desired, such as polymer smoothing layers, scratch resistant layers, antireflective coatings, or other functional layers.

10 The present invention also involves a method of making the barrier assembly. The method includes providing a substrate, and placing at least one barrier stack on the substrate. The barrier stack includes at least one barrier layer and at least one polymer layer.

The at least one barrier stack can be placed on the substrate by deposition,  
15 preferably vacuum deposition, or by laminating the barrier stack over the environmentally sensitive device. The lamination can be performed using an adhesive, solder, ultrasonic welding, pressure, or heat.

Accordingly, it is an object of the present invention to provide a barrier assembly, and to provide a method of making such a barrier assembly.

20 Fig. 1 is a cross-section of one embodiment of the barrier assembly of the present invention.

Fig. 2 is a cross-section of an encapsulated device made using the barrier assembly of the present invention.

One embodiment of the barrier assembly of the present invention is shown in  
25 Fig. 1. The barrier assembly is supported by a substrate 105. The substrate 105 can be either rigid or flexible. A flexible substrate can be any flexible material, including, but not limited to: polymers, for example, polyethylene terephthalate (PET), polyethylene naphthalate (PEN), or high temperature polymers, such as polyether sulfone (PES), polyimides, or Transphan™ (a high glass transition  
30 temperature cyclic olefin polymer available from Lofotech Film, GMBH of Weil

-4-

am Rhein, Germany); metal; paper; fabric; and combinations thereof. Rigid substrates are preferably glass, metal, or silicon.

There are scratch resistant layers 110 on either side of the substrate 105 to protect it. When a scratch resistant layer is included, it is preferred that both sides of the substrate have a scratch resistant layer. This helps to balance stresses and prevent deformation of a flexible substrate during processing and use.

On top of the scratch resistant layer 110, there is a polymer smoothing layer 115. The polymer smoothing layer decreases surface roughness, and encapsulates surface defects, such as pits, scratches, and digs. This produces a planarized surface which is ideal for subsequent deposition of layers. Depending on the desired application, there can be additional layers deposited on the substrate 105, such as organic or inorganic layers, planarizing layers, electrode layers, antireflective coatings, and other functional layers. In this way, the substrate can be specifically tailored to different applications.

The first barrier stack 120 is adjacent to the polymer smoothing layer 115. The first barrier stack 120 includes a barrier layer 125 and a polymer layer 130. The first barrier layer 125 includes barrier layers 135 and 140. Barrier layers 135 and 140 can be made of the same barrier material or of different barrier materials.

Although Fig. 1 shows a barrier stack with two barrier layers and one polymer layer, the barrier stacks can have one or more polymer layers and one or more barrier layers. There could be one polymer layer and one barrier layer, there could be one or more polymer layers on one side of one or more barrier layers, or there could be one or more polymer layers on both sides of one or more barrier layers. The important feature is that the barrier stack have at least one polymer layer and at least one barrier layer. The barrier layers and polymer layers in the barrier stack can be made of the same material or of a different material. The barrier layers are typically about 100-400 Å thick, and the polymer layers are typically about 1000-10,000 Å thick.

Although only one barrier stack is shown in Fig. 1, the number of barrier stacks is not limited. The number of barrier stacks needed depends on the substrate material used and the level of permeation resistance needed for the particular

-5-

application. One or two barrier stacks should provide sufficient barrier properties for some applications. The most stringent applications may require five or more barrier stacks.

There is a transparent conductor 145, such as an indium tin oxide layer,  
5 adjacent to the first barrier stack 120. There can be additional overcoat layers on top of the barrier stack, such as organic or inorganic layers, planarizing layers, transparent conductors, antireflective coatings, or other functional layers, if desired. This allows the barrier assembly to be tailored to the application.

Fig. 2 shows a barrier assembly being used to encapsulate an  
10 environmentally sensitive display device. The substrate 205 has an environmentally sensitive display device 210 on it. There is a barrier stack 215 over the environmentally sensitive display device 210 encapsulating it. The barrier stack 215 includes a barrier layer 220 and a polymer layer 225.

The environmentally sensitive display device 210 can be any display device  
15 which is environmentally sensitive. Examples of environmentally sensitive display devices include, but are not limited to liquid crystal displays (LCDs), light emitting diodes (LEDs), light emitting polymers (LEPs), electronic signage using electrophoretic inks, electroluminescent devices (EDs), and phosphorescent devices. These display devices can be made using known techniques, such as  
20 those described in U.S. Patent Nos. 6,025,899, 5,995,191, 5,994,174, 5,956,112 (LCDs); U.S. Patent Nos. 6,005,692, 5,821,688, 5,747,928 (LEDs); U.S. Patent Nos. 5,969,711, 5,961,804, 4,026,713 (E Ink); U.S. Patent Nos. 6,023,373, 6,023,124, 6,023,125 (LEPs); and U.S. Patent Nos. 6,023,073, 6,040,812, 6,019,654, 6,018,237, 6,014,119, 6,010,796 (EDs), which are incorporated herein by reference.

25 The method of making the barrier assembly will be described with reference to Figs. 1 and 2. Any initial layers which are desired, such as scratch resistant layers, planarizing layers, electrically conductive layers, etc., can be coated, deposited, or otherwise placed on the substrate. A polymer smoothing layer is preferably included to provide a smooth base for the remaining layers. It can be  
30 formed by depositing a layer of polymer, for example, an acrylate-containing polymer, onto the substrate or previous layer. The polymer layer can be deposited in

vacuum or by using atmospheric processes such as spin coating and/or spraying. Preferably, an acrylate-containing monomer, oligomer, or resin is deposited and then polymerized *in situ* to form the polymer layer. As used herein, the term acrylate-containing monomer, oligomer, or resin includes acrylate-containing monomers, oligomers, and resins, methacrylate-containing monomers, oligomers, and resins, and combinations thereof.

The barrier stack is then placed on the substrate. The barrier stack includes at least one barrier layer and at least one polymer layer. The barrier stacks are preferably made by vacuum deposition. The barrier layer can be vacuum deposited onto the polymer smoothing layer, the substrate, or the previous layer. The polymer layer is then deposited on the barrier layer, preferably by flash evaporating acrylate-containing monomers, oligomers, or resins, condensing on the barrier layer, and polymerizing *in situ* in a vacuum chamber. U.S. Patent Nos. 5,440,446 and 5,725,909, which are incorporated herein by reference, describe methods of depositing thin film, barrier stacks.

Vacuum deposition includes flash evaporation of acrylate-containing monomer, oligomer, or resin with *in situ* polymerization under vacuum, plasma deposition and polymerization of acrylate-containing monomer, oligomer, or resin, as well as vacuum deposition of the barrier layers by sputtering, chemical vapor deposition, plasma enhanced chemical vapor deposition, evaporation, sublimation, electron cyclotron resonance-plasma enhanced vapor deposition (ECR-PECVD), and combinations thereof.

In order to protect the integrity of the barrier layer, the formation of defects and/or microcracks in the deposited layer subsequent to deposition and prior to downstream processing should be avoided. The barrier assembly is preferably manufactured so that the barrier layers are not directly contacted by any equipment, such as rollers in a web coating system, to avoid defects that may be caused by abrasion over a roll or roller. This can be accomplished by designing the deposition system such that the barrier layers are always covered by polymer layers prior to contacting or touching any handling equipment.

-7-

When the barrier stack is being used to encapsulate an environmentally sensitive display device, the substrate can be prepared as described above, and the environmentally sensitive display device placed on the substrate. Alternatively, the environmentally sensitive display device can be placed directly on a substrate (or on  
5 a substrate with functional layers, such as planarizing layers, scratch resistant layers, etc.).

The environmentally sensitive display device can be placed on the substrate by deposition, such as vacuum deposition. Alternatively it can be placed on the substrate by lamination. The lamination can use an adhesive, glue, or the like, or  
10 heat to seal the environmentally sensitive display device to the substrate.

A barrier stack is then placed over the environmentally sensitive display device to encapsulate it. The second barrier stack can be placed over the environmentally sensitive display device by deposition or lamination.

The barrier layers in the first and second barrier stacks may be any barrier  
15 material. The barrier layers in the first and second barrier stacks can be made of the same material or a different material. In addition, multiple barrier layers of the same or different barrier materials can be used in a barrier stack.

The barrier layers can be transparent or opaque, depending on the design of the packaging, and application for which it is to be used. Preferred transparent  
20 barrier materials include, but are not limited to, metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof. The metal oxides are preferably selected from silicon oxide, aluminum oxide, titanium oxide, indium oxide, tin oxide, indium tin oxide, tantalum oxide, zirconium oxide, niobium oxide, and combinations thereof. The metal nitrides are preferably selected from  
25 aluminum nitride, silicon nitride, boron nitride, and combinations thereof. The metal oxynitrides are preferably selected from aluminum oxynitride, silicon oxynitride, boron oxynitride, and combinations thereof.

Opaque barrier layers can be also be used in some barrier stacks. Opaque barrier materials include, but are not limited to, metals, ceramics, polymers, and  
30 cermets. Examples of opaque cermets include, but are not limited to, zirconium



-8-

nitride, titanium nitride, hafnium nitride, tantalum nitride, niobium nitride, tungsten disilicide, titanium diboride, and zirconium diboride.

The polymer layers of the first and second barrier stacks are preferably acrylate-containing monomers, oligomers, or resins. The polymer layers in the first  
5 and second barrier stacks can be the same or different. In addition, the polymer layers within each barrier stack can be the same or different.

In a preferred embodiment, the barrier stack includes a polymer layer and two barrier layers. The two barrier layers can be made from the same barrier material or from different barrier materials. The thickness of each barrier layer in this  
10 embodiment is about one half the thickness of the single barrier layer, or about 50 to 200 Å. There are no limitations on the thickness, however.

When the barrier layers are made of the same material, they can be deposited either by sequential deposition using two sources or by the same source using two passes. If two deposition sources are used, deposition conditions can be  
15 different for each source, leading to differences in microstructure and defect dimensions. Any type of deposition source can be used. Different types of deposition processes, such as magnetron sputtering and electron beam evaporation, can be used to deposit the two barrier layers.

The microstructures of the two barrier layers are mismatched as a result of  
20 the differing deposition sources/parameters. The barrier layers can even have different crystal structure. For example,  $\text{Al}_2\text{O}_3$  can exist in different phases (alpha, gamma) with different crystal orientations. The mismatched microstructure can help decouple defects in the adjacent barrier layers, enhancing the tortuous path for gases and water vapor permeation.

25 When the barrier layers are made of different materials, two deposition sources are needed. This can be accomplished by a variety of techniques. For example, if the materials are deposited by sputtering, sputtering targets of different compositions could be used to obtain thin films of different compositions. Alternatively, two sputtering targets of the same composition could be used but with  
30 different reactive gases. Two different types of deposition sources could also be

-9-

used. In this arrangement, the lattices of the two layers are even more mismatched by the different microstructures and lattice parameters of the two materials.

A single pass, roll-to-roll, vacuum deposition of a three layer combination on a PET substrate, i.e., PET substrate/polymer layer/barrier layer/polymer layer, can be more than five orders of magnitude less permeable to oxygen and water vapor than a single oxide layer on PET alone. See J.D.Affinito, M.E.Gross, C.A.Coronado, G.L.Graff, E.N.Greenwell, and P.M.Martin, Polymer-Oxide Transparent Barrier Layers Produced Using PML Process, 39<sup>th</sup> Annual Technical Conference Proceedings of the Society of Vacuum Coaters, Vacuum Web Coating Session, 1996, pages 392-397; J.D.Affinito, S.Eufinger, M.E.Gross, G.L.Graff, and P.M.Martin, PML/Oxide/PML Barrier Layer Performance Differences Arising From Use of UV or Electron Beam Polymerization of the PML Layers, Thin Solid Films, Vol.308, 1997, pages 19-25. This is in spite of the fact that the effect on the permeation rate of the polymer multilayers (PML) layers alone, without the barrier layer (oxide, metal, nitride, oxynitride) layer, is barely measurable. It is believed that the improvement in barrier properties is due to two factors. First, permeation rates in the roll-to-roll coated oxide-only layers were found to be conductance limited by defects in the oxide layer that arose during deposition and when the coated substrate was wound up over system idlers/rollers. Asperities (high points) in the underlying substrate are replicated in the deposited inorganic barrier layer. These features are subject to mechanical damage during web handling/take-up, and can lead to the formation of defects in the deposited film. These defects seriously limit the ultimate barrier performance of the films. In the single pass, polymer/barrier/polymer process, the first acrylic layer planarizes the substrate and provides an ideal surface for subsequent deposition of the inorganic barrier thin film. The second polymer layer provides a robust "protective" film that minimizes damage to the barrier layer and also planarizes the structure for subsequent barrier layer (or environmentally sensitive display device) deposition. The intermediate polymer layers also decouple defects that exist in adjacent inorganic barrier layers, thus creating a tortuous path for gas diffusion.

-10-

The permeability of the barrier stacks used in the present invention is shown in Table 1. The barrier stacks of the present invention on polymeric substrates, such as PET, have measured oxygen transmission rate (OTR) and water vapor transmission rate (WVTR) values well below the detection limits of current industrial instrumentation used for permeation measurements (Mocon OxTran 2/20L and Permatran). Table 1 shows the OTR and WVTR values (measured according to ASTM F 1927-98 and ASTM F 1249-90, respectively) measured at Mocon (Minneapolis, MN) for several barrier stacks on 7 mil PET, along with reported values for other materials.

Table 1

| Sample  | Oxygen Permeation<br>Rate (cc/m <sup>2</sup> /day) |         | Water Vapor<br>Permeation (g/m <sup>2</sup> /day)* |         |
|---|--|---------|--|---------|
|   | 23°C   | 38°C    | 23°C   | 38°C    |
| Native 7 mil PET  | 7.62   | -       | -  | -       |
| 1-barrier stack   | <0.005   | <0.005* | -  | 0.46*   |
| 1-barrier stack with ITO  | <0.005   | <0.005* | -  | 0.011*  |
| 2-barrier stacks  | <0.005   | <0.005* | -  | <0.005* |
| 2-barrier stacks with ITO   | <0.005   | <0.005* | -  | <0.005* |
| 5-barrier stacks  | <0.005   | <0.005* | -  | <0.005* |
| 5-barrier stacks with ITO   | <0.005   | <0.005* | -  | <0.005* |
| DuPont film <sup>1</sup><br>(PET/Si <sub>3</sub> N <sub>4</sub> or PEN/Si <sub>3</sub> N <sub>4</sub> ) | 0.3  | -       | -  | -       |
| Polaroid <sup>3</sup>   | <1.0   | -       | -  | -       |
| PET/Al <sup>2</sup>   | 0.6  | -       | 0.17   | -       |
| PET/silicon oxide <sup>2</sup>  | 0.7 – 1.5  | -       | 0.15 – 0.9   | -       |
| Teijin LCD film<br>(HA grade - TN/STN) <sup>3</sup>   | <2   | -       | <5   | -       |

(\*) 38°C, 90% RH, 100% O<sub>2</sub>

(+\*) 38°C, 100% RH

1 - P. F. Carcia, 46<sup>th</sup> International Symposium of the American Vacuum Society, Oct. 19992 - Langowski, H.C., 39<sup>th</sup> Annual Technical Conference Proceedings, SVC, pp. 398-401 (1996)

3 - Technical Data Sheet

As the data in Table 1 shows, the barrier stacks of the present invention provide oxygen and water vapor permeation rates several orders of magnitude better than PET coated with aluminum, silicon oxide, or aluminum oxide. Typical oxygen permeation rates for other barrier coatings range from about 1 to about 0.1

-11-

cc/m<sup>2</sup>/day. The oxygen transmission rate for the barrier stacks of the present invention is less than 0.005 cc/m<sup>2</sup>/day at 23°C and 0% relative humidity, and at 38°C and 90% relative humidity. The water vapor transmission rate is less than 0.005 g/m<sup>2</sup>/day at 38°C and 100% relative humidity. The actual transmission rates are lower, but cannot be measured with existing equipment.

The barrier assemblies were also tested by encapsulating organic light emitting devices using the barrier stacks of the present invention. The organic light emitting devices are extremely sensitive to water vapor, and they are completely destroyed in the presence of micromole quantities of water vapor. Experimentation and calculations suggest that the water vapor transmission rate through the encapsulation film must be on the order of about 10<sup>-6</sup> to 10<sup>-5</sup> g/m<sup>2</sup>/day to provide sufficient barrier protection for acceptable device lifetimes. The experiments/calculations are based on the detrimental hydrolysis reaction of water vapor with the extremely thin (less than 10 nm), low work function, cathode materials (Ca, Mg, Li, LiF). Hydrolysis of the cathode leads to the formation of non-conductive reaction products (such as hydroxides and oxides) that delaminate or blister away from the electron transport layers of the organic light emitting devices, resulting in the formation of dark spots on the device.

The organic light emitting devices encapsulated in the barrier stacks of the present invention have been in operation for over six months without measurable degradation. The extrapolated lifetime for the encapsulated devices exceeds the required 10,000 hours necessary to satisfy industry standards. The barrier stacks are extremely effective in preventing oxygen and water penetration to the underlying components, substantially outperforming other thin-film barrier coatings on the market.

The preferred deposition process is compatible with a wide variety of substrates. Because the preferred process involves flash evaporation of a monomer and magnetron sputtering, deposition temperatures are well below 100°C, and stresses in the coating can be minimized. Multilayer coatings can be deposited at high deposition rates. No harsh gases or chemicals are used, and the process can be scaled up to large substrates and wide webs. The barrier properties of the coating can be tailored to the application by controlling the number of layers, the

-12-

materials, and the layer design. Thus, the present invention provides a barrier stack with the exceptional barrier properties necessary for hermetic sealing of an environmentally sensitive display device, or other environmentally sensitive device. It permits the production of an encapsulated environmentally sensitive display

5 device.

While certain representative embodiments and details have been shown for purposes of illustrating the invention, it will be apparent to those skilled in the art that various changes in the compositions and methods disclosed herein may be made without departing from the scope of the invention, which is defined in the appended

10 claims.

-13-

## CLAIMS

1. A barrier assembly comprising:  
at least one barrier stack comprising at least one barrier layer and at least one polymer layer, wherein the at least one barrier stack has an oxygen  
5 transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 23°C and 0% relative humidity
2. The barrier assembly of claim 1 wherein the at least one barrier stack has an oxygen transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 38°C and 90% relative humidity.
3. The barrier assembly of claim 1 wherein the at least one barrier stack has a  
10 water vapor transmission rate of less than 0.005 g/m<sup>2</sup>/day at 38°C and 100% relative humidity.
4. The barrier assembly of claim 1 further comprising a substrate adjacent to the at least one barrier stack.
5. The barrier assembly of claim 1 wherein the at least one barrier layer is  
15 substantially transparent.
6. The barrier assembly of claim 1 wherein at least one of the at least one barrier layer comprises a material selected from metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof.
7. The barrier assembly of claim 6 wherein the metal oxides are selected from  
20 silicon oxide, aluminum oxide, titanium oxide, indium oxide, tin oxide, indium tin oxide, tantalum oxide, zirconium oxide, niobium oxide, and combinations thereof.
8. The barrier assembly of claim 6 wherein the metal nitrides are selected from aluminum nitride, silicon nitride, boron nitride, and combinations thereof.

-14-

9. The barrier assembly of claim 6 wherein the metal oxynitrides are selected from aluminum oxynitride, silicon oxynitride, boron oxynitride, and combinations thereof.
10. The barrier assembly of claim 1 wherein the at least one first barrier layer is  
5 substantially opaque.
11. The barrier assembly of claim 1 wherein at least one of the at least one first barrier layers is selected from opaque metals, opaque polymers, opaque ceramics, and opaque cermets.
12. The barrier assembly of claim 4 wherein the substrate comprises a flexible  
10 substrate material.
13. The barrier assembly of claim 12 wherein the flexible substrate material is selected from polymers, metals, paper, fabric, and combinations thereof.
14. The barrier assembly of claim 4 wherein the substrate comprises a rigid substrate material.
15. 15. The barrier assembly of claim 14 wherein the rigid substrate material is selected from ceramics, metals, and semiconductors.
16. The barrier assembly of claim 1 wherein at least one of the at least one polymer layers comprises an acrylate-containing polymer.
17. The barrier assembly of claim 4 further comprising a polymer smoothing layer  
20 adjacent to the substrate.
18. The barrier assembly of claim 4 further comprising a scratch resistant layer adjacent to the substrate.

-15-

19. The barrier assembly of claim 1 further comprising an anti-reflective coating adjacent to the substrate.
20. The barrier assembly of claim 1 further comprising an anti-fingerprint coating adjacent to the substrate.
- 5 21. The barrier assembly of claim 1 further comprising an anti-static coating adjacent to the substrate.
22. The barrier assembly of claim 1 wherein the at least one barrier layer comprises two barrier layers.
23. The barrier assembly of claim 22 wherein the two barrier layers are made of  
10 the same barrier material.
24. The barrier assembly of claim 22 wherein the two barrier layers are made of different barrier materials.
25. A method of making a barrier assembly comprising:  
providing a substrate; and  
15 placing at least one first barrier stack comprising at least one first barrier layer and at least one first polymer layer on the substrate, wherein the at least one barrier stack has an oxygen transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 23°C and 0% relative humidity.
26. The method of claim 25 wherein the at least one barrier stack has an oxygen transmission rate of less than 0.005 cc/m<sup>2</sup>/day at 38°C and 90% relative humidity.
27. The method of claim 25 wherein the at least one barrier stack has an water vapor transmission rate of less than 0.005 g/m<sup>2</sup>/day at 38°C and 100% relative humidity.



-16-

28. The method of claim 25 wherein the step of placing the at least one barrier stack on the substrate comprises depositing the at least one barrier stack on the substrate.

29. The method of claim 28 wherein the at least one barrier stack is vacuum  
5 deposited.

30. The method of claim 28 wherein the at least one barrier layer is vacuum deposited and the at least one polymer layer is deposited.

31. The method of claim 28 wherein the step of placing the at least one barrier stack on the substrate comprises laminating the at least one barrier stack on the  
10 substrate.

32. The method of claim 31 wherein the at least one barrier stack is laminated using an adhesive.

33. The method of claim 31 wherein the at least one barrier stack is laminated using heat.

15 34. The method of claim 31 wherein the at least one barrier stack is laminated using solder.

35. The method of claim 31 wherein the at least one barrier stack is laminated using ultrasonic welding.

36. The method of claim 31 wherein the at least one barrier stack is laminated  
20 using pressure.

37. The method of claim 25 further comprising depositing a polymer smoothing layer on the substrate before the at least one barrier stack is placed thereon.

-17-

38. The method of claim 25 further comprising depositing a scratch resistant layer on the substrate before the at least one barrier stack is placed thereon.

39. The method of claim 25 further comprising depositing an anti-reflective coating on the substrate before the at least one barrier stack is placed thereon.

5 40. The method of claim 25 further comprising depositing an anti-fingerprint coating on the substrate before the at least one barrier stack is placed thereon.

41. The method of claim 25 further comprising depositing an anti-static coating on the substrate before the at least one barrier stack is placed thereon.

42. The method of claim 25 wherein the at least one barrier layer comprises two  
10 barrier layers.

43. The method of claim 42 wherein the two barrier layers are deposited using the same deposition source.

44. The method of claim 42 wherein the two barrier layers are deposited using different deposition sources.

15 45. The method of claim 42 wherein the two barrier layers are vacuum deposited.

46. The method of claim 42 wherein the two barrier layers are made of the same barrier material.

47. The method of claim 42 wherein the two barrier layers are made of different  
20 barrier materials.

1/1

FIG. 1

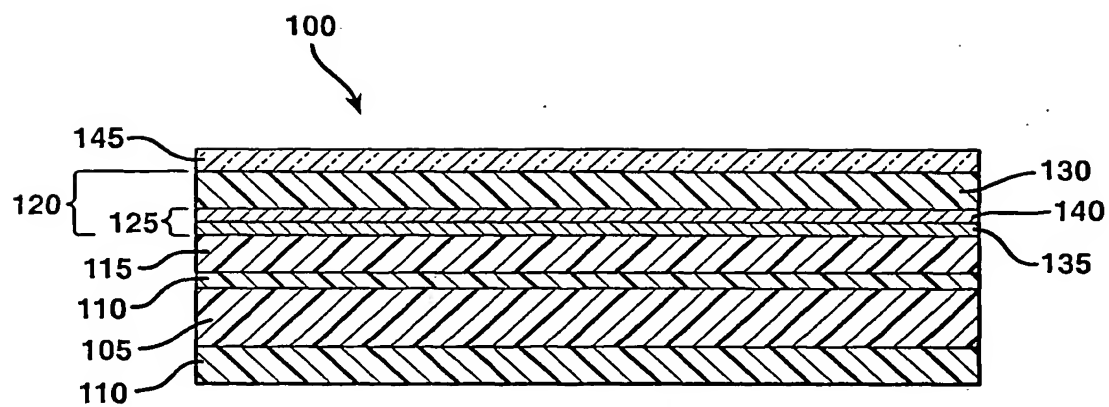
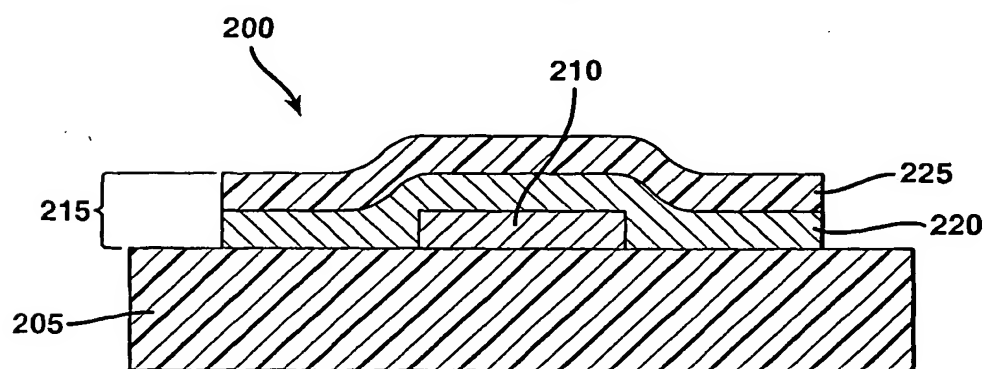


FIG. 2



# INTERNATIONAL SEARCH REPORT

International Application No  
PC, JS 01/06596

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 C23C14/08 B05D7/24 B65D65/40

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 B05D C23C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data, IBM-TDB, INSPEC, COMPENDEX

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No.                     |
|------------|---|---|
| X          | AFFINITO J D ET AL: "A new method for fabricating transparent barrier layers"<br>23RD INTERNATIONAL CONFERENCE ON METALLURGICAL COATINGS AND THIN FILMS, SAN DIEGO, CA, USA, 22-26 APRIL 1996, vol. 290-291, pages 63-67, XP004173291<br>Thin Solid Films, 15 Dec. 1996, Elsevier, Switzerland<br>ISSN: 0040-6090 | 1-7,<br>12-14,<br>25-30,<br>37-41         |
| Y          | table 1   | 8-11,<br>16-24,<br>28,<br>31-36,<br>42-47 |
| Y          | EP 0 787 824 A (BECTON DICKINSON CO)<br>6 August 1997 (1997-08-06)<br>the whole document  | 16-23,<br>42-47                           |
|            | ---<br>-/--   |   |

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

\*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

\*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

\*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

\*&\* document member of the same patent family

Date of the actual completion of the international search

28 August 2001

Date of mailing of the international search report

05/09/2001

Name and mailing address of the ISA  
European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Ekhult, H

# INTERNATIONAL SEARCH REPORT

International Application No  
PC1/US 01/06596

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No.              |
|------------|--|------------------------------------|
| Y          | US 5 607 789 A (TREGER JACK ET AL)<br>4 March 1997 (1997-03-04)<br>cited in the application<br><br>column 3, line 25 -column 5, line 36<br>column 7, line 13 - line 36; example 3<br>---   | 22, 24,<br>28,<br>31-36,<br>42, 47 |
| Y          | US 5 736 207 A (HEMING MARTIN ET AL)<br>7 April 1998 (1998-04-07)<br>column 2, line 10 - line 64<br>---  | 8-11                               |
| A          | AFFINITO J D ET AL: "PML/oxide/PML<br>barrier layer performance differences<br>arising from use of UV or electron beam<br>polymerization of the PML layers"<br>24TH INTERNATIONAL CONFERENCE ON<br>METALLURGICAL COATINGS AND THIN FILMS, SAN<br>DIEGO, CA, USA, 21-25 APRIL 1997,<br>vol. 308-309, pages 19-25, XP004110238<br>Thin Solid Films, 31 Oct. 1997, Elsevier,<br>Switzerland<br>ISSN: 0040-6090<br>cited in the application<br>figure 1<br>--- | 1-47                               |
| A          | GB 2 210 826 A (BOWATER PACKAGING LTD)<br>21 June 1989 (1989-06-21)<br>examples 3-6<br>---   | 1-47                               |
| A          | US 5 440 446 A (SHAW DAVID G ET AL)<br>8 August 1995 (1995-08-08)<br>cited in the application<br>column 6, line 53 -column 7, line 68<br>---   | 1-47                               |
| A          | US 5 376 467 A (ABE TAKAO ET AL)<br>27 December 1994 (1994-12-27)<br>column 3, line 8 - line 25<br>---   | 31-36                              |
| P, X       | WO 00 26973 A (BRIGHT CLARK I ;DELTA V<br>TECHNOLOGIES INC (US))<br>11 May 2000 (2000-05-11)<br>page 12, line 20 -page 13, line 9<br>-----   | 1, 25                              |

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PC 1, 03 01/06596

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|---|---------------------|----------------------------|---------------------|
| EP 0787824 A                              | 06-08-1997          | AU 1235497 A               | 07-08-1997          |
|   |                     | BR 9700743 A               | 06-10-1998          |
|   |                     | CA 2194318 A               | 31-07-1997          |
|   |                     | JP 9324137 A               | 16-12-1997          |
|   |                     | KR 219874 B                | 01-09-1999          |
|   |                     | SG 67969 A                 | 19-10-1999          |
| US 5607789 A                              | 04-03-1997          | AU 691092 B                | 07-05-1998          |
|   |                     | AU 4857296 A               | 14-08-1996          |
|   |                     | BG 101818 A                | 30-04-1998          |
|   |                     | BR 9606781 A               | 30-12-1997          |
|   |                     | CA 2210232 A               | 01-08-1996          |
|   |                     | CN 1176695 A               | 18-03-1998          |
|   |                     | CZ 9702211 A               | 15-04-1998          |
|   |                     | EP 0820588 A               | 28-01-1998          |
|   |                     | IL 116639 A                | 30-10-1998          |
|   |                     | JP 10513003 T              | 08-12-1998          |
|   |                     | NO 973379 A                | 12-09-1997          |
|   |                     | NZ 302500 A                | 28-07-1998          |
|   |                     | PL 321474 A                | 08-12-1997          |
|   |                     | RU 2142626 C               | 10-12-1999          |
|   |                     | WO 9623217 A               | 01-08-1996          |
|   |                     | US 5681666 A               | 28-10-1997          |
| US 5736207 A                              | 07-04-1998          | DE 4438359 A               | 02-05-1996          |
|   |                     | AT 172754 T                | 15-11-1998          |
|   |                     | CA 2161362 A               | 28-04-1996          |
|   |                     | DE 59504059 D              | 03-12-1998          |
|   |                     | DK 709485 T                | 12-07-1999          |
|   |                     | EP 0709485 A               | 01-05-1996          |
|   |                     | ES 2123872 T               | 16-01-1999          |
|   |                     | JP 8318590 A               | 03-12-1996          |
|   |                     | US 5900285 A               | 04-05-1999          |
| GB 2210826 A                              | 21-06-1989          | GB 2246794 A,B             | 12-02-1992          |
|   |                     | GB 2246795 A,B             | 12-02-1992          |
| US 5440446 A                              | 08-08-1995          | AU 694143 B                | 16-07-1998          |
|   |                     | AU 7965594 A               | 01-05-1995          |
|   |                     | BR 9407741 A               | 12-02-1997          |
|   |                     | EP 0758482 A               | 19-02-1997          |
|   |                     | EP 0722787 A               | 24-07-1996          |
|   |                     | FI 961478 A                | 02-04-1996          |
|   |                     | JP 8512256 T               | 24-12-1996          |
|   |                     | JP 3101682 B               | 23-10-2000          |
|   |                     | JP 2000235930 A            | 29-08-2000          |
|   |                     | KR 241470 B                | 01-02-2000          |
|   |                     | WO 9510117 A               | 13-04-1995          |
|   |                     | US 5725909 A               | 10-03-1998          |
|   |                     | US 6231939 B               | 15-05-2001          |
|   |                     | US 2001001284 A            | 17-05-2001          |
| US 5376467 A                              | 27-12-1994          | JP 5251076 A               | 28-09-1993          |
| WO 0026973 A                              | 11-05-2000          | AU 1339700 A               | 22-05-2000          |